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Gendered emissions? Rethinking empowerment and environmental outcomes across income divides

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Abstract

This study seeks to test the hypothesis that gender empowerment impacts environmental outcomes by opening a window into the ways female legal and political representation affects carbon dioxide emissions in lower- and higher-income countries. The implementation of dynamic panel data models (Arellano-Bond GMM) reveals that emissions boast considerable persistence over time, with such persistence ranging from a lagged CO_2 term of 0.330 in lower-income to 0.396 in higher-income countries. Industrial activity in lower-income contexts is shown to be an emission driver, whereas population density is a prominent driver in higher-income contexts. The Women, Business and the Law index has a significant effect only in higher-income countries, driving up emissions by approximately 0.8 percent for each unit increase, which indicates that gender-inclusive legal structures go hand in hand with economic structures prone to high emissions in more developed economies. In contrast, the parliamentary share of women has a small yet significantly positive effect on emissions in lower-income countries only (coefficient of 0.006), suggesting another possibility that political representation may somehow lead to industrial development and its associated emissions during the early stages. No significant link is established for GDP growth in either income group whenever political representation is selected as the gender indicator, revealing that the growth-emission relationship actually varies depending on the gender measure selected. These results strongly suggest how gender empowerment interacts with emissions trajectories through myriad context-specific ways, and thus there is a clear call for integrated policy attention marrying the goals of gender equity and environmental sustainability.

Keywords: Gender empowerment; Women in parliament; CO_2 emissions; Dynamic panel data; Arellano-Bond GMM; Industrial activity; Urbanization; Environmental policy

1. Introduction

The environmental sustainability movement, combined with the fight for social justice, as of late has managed to turn the heads of many academicians and politicians. One of the existing streams of this complex discussion is devoted to the elevation of women as factors of change with regard to the environment. Such affirmative action aims at improving the status of women not only in a few narrow quantitative indicators of development but also enhances the quality of their decision-making at the household, community and the national levels [1, 2]. A few benefits were recorded from the results of the women's National Assembly participation in decision-making which include increased attention to and representation of women in the generation and allocation of European World Heritage [2, 3].

Also few studies have attempted to estimate gender's secondary effects, and, as expected, the substantial economic and societal benefits of empowering women have been less studied – or have produced less conclusive evidence. For instance, studies have explored factors leading to fundamental disproportionate emissions across countries and one such notable reasons is the level of female education. Somoye and Akinwande resolve that in the context of Nigeria, female education and renewable energy consumption are negatively related to CO_2 generation indicating the various

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areas intersecting gender aspects and environmental considerations in a country. The approach is centred on the discussion of the potential factors contributing towards advancement or decreasing emissions from female education and the introduction of renewable energy in countries like Nigeria for instance [5]. This study goes about to investigate how policies aiming to improve the status of women like education may, again, contrary to expectations, increase emissions of gases, in this case CO2, in high school girls in Kenya [24].

The scope of this paper seeks to explain several questions such gender inclusion, economic development in only energy efficient country or sector and its association with environmental sustainability, as well as other dimensions, assists in understanding the socio-economic environment such as the above indicators. The paper touches upon environmental issues and the participation of women in various levels of policymaking as it explores coverage of the gender and development perspective to the study of climate change adaptation issues. Further, the paper attempts to address climate change gender issues and the economic growth of a particular country within time and resource constraints.

2. Literature Review

Emerging literature contends that women's empowerment is a resource not only desired but is an important catalyst nurturing adaptive capacity, environmental allegiance, and environmental resource management that is capable if sustainability. Aman et al. make this very argument tackling the measurement of climate vulnerability with an emphasis on the Pakistani population and consider how the gendered aspect of these algorithms helps rural women, in particular, who far from sharing in the society's resources are grappling with things like food insecurity, lack energy and health and even working findings reveal [6]. It comes more clearly on the importance of both incorporating adaptor measures that pay attention to gender and promoting female power along with enhancing the environment and sustainable livelihood including representing communities in climate change mitigation and planning crucial constraints to adoption.

The study by Mushtaq and Afzal covering countries in South Asia also suggests that this is in line. Using the Cross-sectional ARDL model, they find that women's empowerment leads the early years model decrease in climate vulnerability, which results from political and civil aspects of the anticlimate change hurdles, among other impediments to empowerment [7]. However, this reduction is bound to the structural power of collaborating agents and decision-making process that si all wrapped up in the argument that there is no regime that can offer resilience and functional in nature without being gender mainstreamed. Lucas, in a systematic review of evidence focuses on different ways in which gender can be used positive and negatively to impact environmental outcomes. Among which are the involvement of women in political leadership, education, reproductive health as well as land tenure security and the positive implications of these activities and which include weak or no deforestation and emission of less CO_2, better management of water resources and so forth [8]. While establishing causality is a huge challenge and often depends on the specifics of the problem at hand, at macro level one issue keeps coming up – participatory decision making leads to more sustainable and equitable decisions in the environment where women are part of the process.

Similarly, the micro-level perspective is employed by Damariis's work which specifically devotes to the study of women's participation in the adoption of agroforestry technologies in semi-arid Kenya. It reflects this narrative through integration of cultural practices with modern sciences, in particular, women's traditional ecological knowledge and the role they seem to have in maintaining the ecology of the environment given the challenges associated with climate change [9]. This is supported by Sultana et al. who perceive seaweed farming as a women targeted form of carbon sequestration that can help with food security enhancement for the poor regions especially, the coastal zones [10].

Taking up the concept from another vantage but in a policy perspective, Azu assesses the pre-existing and enhanced discrimination of women in rights-based crisis responses and demands for improved systems of addressing gender discrimination in crises. Social science research which stands against the distinction of gender and analyzes how women are forced through gender, health, security and displacement concerns, to actually participate in the fulfillment of their own oppression. The research concludes that this needs to change and demands that climate politics put women in combating the harmful institution of gender [11].

On a related note, Langnel et al. also looked at how degradation of the environment in Sub-Saharan Africa has impacted the ways in which females participate in the economy. The results show that carbon emissions from water, deforestation and energy sources impede women's productive participation in the labour market especially in the developing countries, suggesting that environmental and gender factors reinforce each other in causing vulnerability in such regions [12].

Consequently, all the above studies lead to a change in the system of climate governance - from authoritative, technocrat and logic to more people-oriented, justice based regimes. Gender has stopped being treated as an issue on the sideline for the other issues pertinent to development, but is being viewed as a strategic imperative for sustainability [24, 25]. The proof presented calls for that truly integrate laws of women, change the distribution of social power and also change operation in the institutions to attend to the needs that are gendered.

3. Methodology

The article uses data from the World Bank Open Database. There were 150 countries throughout 1990–2023. Several explanatory variables are log-transformed prior to estimation. These transformations are applied to reduce skewness in the data, mitigate the influence of extreme values, and improve the linearity of relationships between variables. Logging also facilitates interpretation of the regression coefficients in percentage terms, which is particularly appropriate given the multiplicative nature of many economic and environmental processes. I drop observations with zero or negative values because the logarithm is undefined for non-positive numbers [13]. This procedure ensures that all log-transformed variables are valid for regression analysis.

3.1. Model selection

This study employs the Arellano-Bond Generalized Method of Moments (GMM) estimator to examine the relationship between women's empowerment and environmental footprint, using a dynamic panel data framework. This approach is particularly suitable given the characteristics of the data and the potential econometric challenges associated with the research question [14].

The baseline dynamic model can be specified in formula 1:

$$y_{it} = \alpha\, y_{it-1} + \beta\, X_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

where:

y_{it} is the environmental footprint for country *i* at time *t*,
y_{it-1} is the lagged dependent variable,
X_{it} is a vector of explanatory variables, including indicators of women's empowerment,
μ_i denotes unobserved country-specific effects, and
ε_{it} is the idiosyncratic error term.

Including the lagged dependent variable y_{it-1} captures the temporal dependence of environmental indicators, which often exhibit persistence due to structural and policy inertia (Stern, 2004). However, this inclusion also introduces correlation with the unobserved fixed effects μ_i, resulting in biased estimates if using standard estimators such as fixed effects or pooled OLS [15].

To address this issue, the Arellano-Bond estimator transforms the model through first-differencing, which removes the individual effects as shown in formula 2:

$$\Delta y_{it} = \alpha\, \Delta y_{it-1} + \beta\, \Delta X_{it} + \Delta\varepsilon_{it} \quad (2)$$

While this eliminates the time-invariant unobserved heterogeneity, it introduces potential endogeneity because Δy_{it-1} is correlated with $\Delta\varepsilon_{it}$. To resolve this, the estimator uses lagged levels of the dependent and independent variables as instruments under the assumption that the error term is not serially correlated and the regressors are weakly exogenous.

The moment condition for valid instruments from formula 3 is expressed as:

$$E[X_{i,t-s} \cdot \Delta\varepsilon_{it}] = 0 \quad \text{for } s \geq 2 \quad (3)$$

This setup addresses several empirical concerns. First, the use of y_{it-1} accommodates the dynamic behavior of environmental outcomes. Second, the method corrects for possible endogeneity between women's empowerment and environmental footprint, which may arise from reverse causality or omitted variables. For example, while empowered women can influence environmental policy, environmental conditions may also affect opportunities for empowerment.

Third, by differencing the data, the estimator controls for time-invariant, unobserved country-specific characteristics, such as institutional quality or cultural norms, which could otherwise bias the results. Finally, the Arellano-Bond estimator is particularly well-suited for panel data with a large number of cross-sectional units (e.g., countries) and a relatively short time dimension, which characterizes the structure of the dataset used in this study.

4. Results and discussion

4.1. Descriptive statistics

The descriptive statistics in Table 1 show wide variation in CO_2 emissions per capita its mean is 4.69, it highlights stark differences in environmental outcomes across countries. Gender empowerment indicators also differ substantially: the proportion of women in national parliaments averages 18.8% and ranges from 0% to 63.75%. The Women, Business and the Law Index has a mean score of 71.23 out of 100, these both reflect unequal access to legal and political rights. These disparities provide a strong empirical basis to examine whether higher gender empowerment contributes to lower emissions.

Other contextual variables such as GDP per capita, industry's share in the GDP, and population density (mean = 194.65 people/km^2) further illustrate the structural and economic differences that may moderate or interact with gender's role in shaping environmental performance.

Table 1 Descriptive Statistics

Variable	Short Name	mean	std	min	max
Annual CO_2 emissions (per capita)	CO2_per_capita	4.69	5.66	0.02	37.57
Proportion of seats held by women in national parliaments (%)	Women_Parliament	18.8	11.56	0	63.75
Women Business and the Law Index Score (scale 1-100)	Women_Law_Index	71.23	17.33	23.75	100
GDP per capita, PPP (constant 2021 international $)	GDP_per_capita	22138.73	23087.54	833.92	137821.4
Industry (including construction), value added (% of GDP)	Industry_GDP	26.57	10.18	2.83	86.67
Population density (people per sq. km of land area)	Pop_Density	194.65	635.57	1.52	7965.88
Foreign direct investment, net inflows (% of GDP)	FDI_GDP	5.93	24.03	-01.83	452.22
Forest area (sq. km)	Forest_area	271573.1	922101.1	0	8153116

Source: author estimations in Python based on the data from the World Bank

4.2. Correlation analysis

Figure 1 presents the Pearson correlation coefficients calculated for the set of variables. The dependent variable of interest, log-transformed CO_2 emissions per capita, is correlated with a set of economic, demographic, environmental, and inclusion-in-gender indicators. Also, the table supplies statistical significance levels, which help to assess the strength and reliability of these observed bivariate associations.

GDP per capita and CO_2 emission per capita strongly and positively correlate (r = 0.75), a common finding in the vast literature relating economic development to environmental degradation. Production activities from the industrial sector share a similar correlation in the positive and significant direction with CO_2 emissions, with r = 0.32, suggesting that the more industrialized economies tend to have higher emissions per capita. This is because industrial production and energy consumption are supposed to be highly emission-intensive.

Of the rest of the demographic and environmental control variables, population density is positively yet weakly correlated to CO_2 emissions (r = 0.10), while forest area shows some modest but significant positive association with it (r = 0.15). The later might be due to the reverse causation or some unaccounted heterogeneity across the countries with vast forest reserves and highly economic activities.

The primary variable of interest, women in parliament (percentage of seats held by women), shows a negative and significant correlation with CO_2 emissions per capita (r = -0.11). This negative linkage suggests that higher female political representation is associated with marginally lower emissions; the reason could be differences in political priorities or variations in environmental governance, or it might be a broader social or institutional effect of more gender-inclusive political systems.

As another indicator of gender inclusion, the Women, Business and the Law Index positively correlates with CO_2 emissions (r = 0.10). This index is also moderately and significantly correlated with GDP per capita (r = 0.38), a factor that could, at least partially, explain its positive correlation with emissions. The result, therefore, does not necessarily infer that business-related gender reforms lead to environmental degradation-it rather points to the difficulty in isolating gender-effects from structural economic factors.

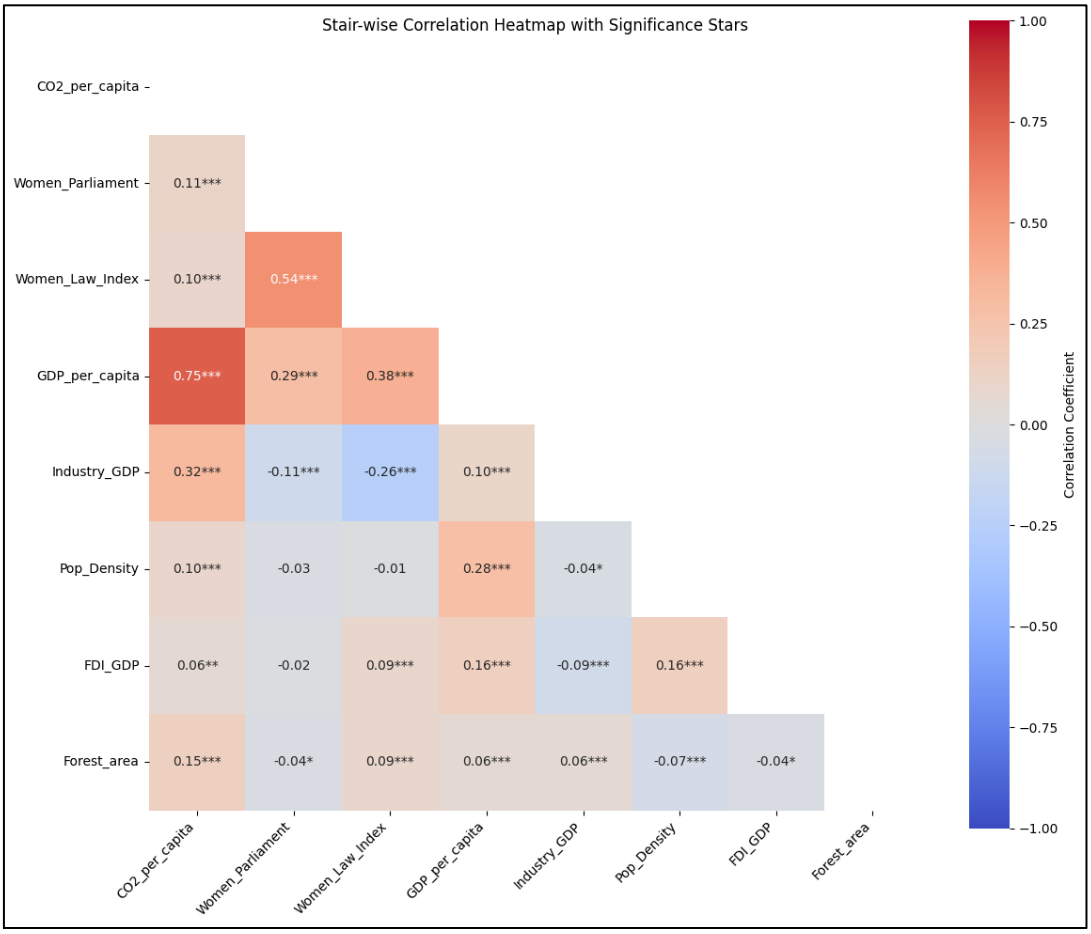

Figure 1 Correlation heat map. Source: author estimations in Python based on the data from the World Bank

4.3. Main results

Table 2 presents the results of the dynamic panel data estimation. CO2 emissions exhibit some persistence over time, with a positive coefficient on the lagged dependent variable, conforming to Stern who posits that typical emission patterns of the past reinforce themselves [16]. The analysis confirms the existence of an Environmental Kuznets Curve [17], where initial economic growth leads to an increase in emissions but this effect gets reversed at higher levels of income. Therefore, a 1% rise in GDP brings about a remarkable decrease in emissions at the beginning, then this effect gets reversed at further higher levels of GDP, meaning that advanced economies could possibly reduce emissions through structural changes and cleaner production.

Industrial activities appear to be an important cause here; a 1% increase in the industrial share causes around 0.08% rise in emissions. Population density has also been positively correlated with emissions, where a 1% increase in density leads to about 1% increase in emissions, thereby illustrating pressures on the environment stemming from urbanization per Cole and Neumayer [18].

Table 2 Arellano-Bond GMM

Variable	**Full dataset**
Lagged CO2_{t-1}	0.252 (0.098)***
WBL_index	0.011 (0.004)***
log(GDP)	-1.415 (0.455)***
log(GDP)^2	0.098 (0.027)***
log(Industry)	0.076 (0.028)***
log(Population Density)	1.008 (0.224)***
FDI	-0.00008 (0.00017)
Forest Area	-0.0000002 (0.0000003)
Observations	1855
Number of Groups (N)	147
Number of Periods (T)	15
Instrument Count	92
AR(1) test (p-value)	0.071*
AR(2) test (p-value)	0.773
Hansen J-test (p-value)	0.250

Source: author estimations in Python based on the data from the World Bank

Conversely, the WBL index has a small positive effect on emissions. With a 1-unit rise in the index, emissions are on the rise by 1.1%, potentially indicating that greater legal and economic opportunities for women also mean more urban-industrial economic structures with higher emissions intensities [19]. Therefore, gender-responsive environmental policy is needed to decouple inclusive development from emissions growth.

On the contrary, the FDI and forest area show no significant direct effects, as also found by York, who concluded that emissions trends tend to be generally dominated by macroeconomic and urban-industrial transitions [20].

In sum, these results highlight the interactions between economics, demographic pressures, and inclusive legal frameworks that shape the trajectories of national emissions. The bigger picture highlights strategies outside the environmental vertical to gird environmental concerns and inclusive growth.

4.4. Robustness check within subsets

The empirical performance of the developed countries' adjustment process represented in table 3 indicates remarkable differences in the causal link mechanisms of CO_2 emissions with other variables particularly if differentiated by income levels. In all the three models applied–that is, the complete estimating equation, the lower-income group and the upper-income group–the lagged CO_2 term reveals statistically significant feature of persistence of the emissions' value in the sense that the relationship holds even when other variables are introduced and improves even further in higher-income countries (0.396) in contrast to the full sample (0.252). It speaks to extensive prevalence of emission trends which is more of an organizational and economic development of the states rather than pollution.

The Women, Business and the Law (WBL) index portrays completely different profile. It is still positively connected with pollution under the base set and, more remarkably, it is highly significant in wealthier countries, whereas it is in the least squares minimization problems for the poorest countries. Hence, it may be a golden opportunity of increasing gender equality at their formal systems in regions where no embedment of economic activities of females has been achieved.

Table 3 Arellano-Bond GMM

Variable	Lower-income countries	Higher-income countries
Lagged CO2_{t-1}	0.330 (0.128)***	0.396 (0.119)***
WBL_index	-0.004 (0.005)	0.008 (0.004)**
log(GDP)	-0.297 (0.509)	0.303 (0.068)***
log(GDP)^2	0.024 (0.031)	0.019 (0.007)***
log(Industry)	0.028 (0.017)*	0.049 (0.078)
log(Population Density)	0.366 (0.229)	0.948 (0.280)***
FDI	0.00057 (0.00059)	-0.00028 (0.00015)**
Forest Area	-0.0000009 (0.0000005)**	-0.0000003 (0.0000003)
Observations	1017	838
Number of Groups (N)	84	63
Number of Periods (T)	15	15
Instrument Count	92	92
AR(1) test (p-value)	0.041**	0.028**
AR(2) test (p-value)	0.560	0.231
Hansen J-test (p-value)	0.851	0.998

Source: author estimations in Python based on the data from the World Bank

As for growth, measured with the help of the polynomials log(GDP) and $\log(GDP)^2$, in the full sample and in the countries with higher incomes, there is a significant non-linear Environmental Kuznets Curve relationship, which however is not found in the lower income countries. Accordingly, it is stated that with increasing economic activity so also emissions increases initially and subsequently declines in more advanced economies since the growth is accompanied with expansion and also improvement of energy efficient technology. In the full dataset and in those regions where the income level is lower, 'industrial activity' is an important driver of emissions, since it is strongly correlated with such e, moreover, weakening does not occur. This pattern corresponds to industrialization that is typically an important engine in the growth and development of less developed countries. In contrast, this correlation loses it salience in high income countries which implies that there is a movement away from this industry to more service-oriented or less emission-intensive otherwise known as clean ways of activities within an economy.

It is clearly shown that population density contributes a lot to emissions as far as the developed countries are concerned, indicating that urbanization enhances environmental degradation, while it more or less tends to have no statistical significance in the low income settings. Finally, foreign direct investment (FDI) and forest area have a very interesting behavior patterns. FDI reduces pollution only in the high income countries because of S&T coordination spillovers [21]; in contrast, the reduction of emissions in the low income countries due to forest covers suggests existence of alternative storage reservoirs of carbon.

4.5. Robustness check with alternative variable

This section informs the results of the dynamic panel language using the proportion of women in the parliament to measure the level of the environment of females and reactions toward the pollution level from table 4. Analyzing carbon dioxide emissions across lower- and higher-income countries might yield translation effects where the intercept series, which may be correlated with the green house gas emissions, interacts with the movement dynamics of the parameters. Of particular concern is the fact that there is an increase in lower-income countries on the relationship between women political representation and emissions, which means that political presence may also be associated with growth in the economy and industry which further increases the emissions. In respect of the higher-income countries, however, no such pattern is observed, which may be due to their less industrial sector driven economies or more stringent environmental regulations.

As contrasted to the previous results using the index of "Women, Business and the Law", the present study does not display a meaningful relationship between economic development and carbon emissions, which is another indication of the variability of the relationship between growth and emissions over different indicators of the gender. In lower-income regions, industrial activity as typically measured in the use of factors that consume fuels and produce flammable gases remains a significant environmental pull, whereas for the well-off countries and magnet vectors prove either weak and worse, in accordance with ideas about fasted green growth such as effective decoupling. But for well-off countries, the pressure being that of urbanism. In upper income countries, high population concentration can also be used an explanation of the high emissions levels.

On the other hand, the expansion of forest area is still considered a positive measure of the growth of emissions in lower income countries and this is due to low carbon density. The diagnostic statistics of Table 4, observed that the Arellano-Bond GMM estimation is accurate and some diagnostic considerations are out of concern. Usually dynamic models have in different time frames so for such models the condition $T<N$ obviously holds at least asymptotically. The instrument count in the higher-income countries model which is close to the groups number is little above within bounds. The high Hansen J-test will result to the over-identification test problem suggesting such environment is absent [22]. The eigenvalue of the autoregressive polynomial cannot be ignored either. The lagged dependent variable in and of itself confirms that the specifications are indeed dynamic. Last but not least, the sample confirms the first moment assumptions for the moment conditions are pertinent. The tests on both AR(1) and AR(2) indicate that the dependence assumption does not hold since p-values are above the usual 0.05 cut-off. Even though the AR(1) test has a p-value above the conventional level of 0.05, this is not a problem to the model since it is normal for data that has been first differed to exhibit first-order autocorrelation. Overall, these diagnostic checks support that the models are satisfactory for quantifying the factors that influence CO2 emission trends according to the income strata.

Table 4 Arellano-Bond GMM

Variable	Lower-income countries	Higher-income countries
Lagged CO2_{t-1}	0.522 (0.270)**	0.301 (0.140)**
Women Parliamentarians	0.006 (0.003)**	0.003 (0.008)
log(GDP)	-0.521 (0.534)	-1.419 (3.344)
log(GDP)^2	0.036 (0.030)	0.115 (0.165)
log(Industry)	0.061 (0.035)*	-0.074 (0.087)
log(Population Density)	0.242 (0.197)	1.399 (0.381)***
FDI	0.00071 (0.00081)	-0.00027 (0.00020)
Forest Area	-0.0000010 (0.0000004)**	-0.0000003 (0.0000004)
Observations	839	717
Number of Groups (N)	84	63
Number of Periods (T)	13	13
Instrument Count	80	80
AR(1) test (p-value)	0.127	0.247
AR(2) test (p-value)	0.343	0.639
Hansen J-test (p-value)	0.886	0.947

5. Conclusion

To summarize, the aim of this research was to find out whether or not gender empowerment has an effect on different outcomes relevant to the environment, such as carbon dioxide emissions, at different income levels. There is indication that gender empowerment alone is not always a driver of emissions reductions but rather interacts with broad economic and structural dynamics in a highly convoluted manner.

The study suggests that female empowerment, in terms of legal-economic measures or political representation, does not necessarily lead to decreases in emission. On the contrary, the results suggest that, amongst richer countries, economies that are more inclusive of women in their legal and economic spheres tend to become more emissions intensive; whereas, in the poorer countries, political representation could coincide with industrial growth (and the emissions that go with it). These somewhat ambiguous patterns warn us against simplistic approaches that assume that an empowered female population will ensure environmentally friendly practices.

Meanwhile, the continued relevance of industrialization and urbanization as forces behind emissions is consistent with the argument that economic and demographic structures figure centrally in environmental outcomes. The variations associated with gender empowerment vis-a-vis these inconsistent structures along income lines highlight the importance of developing context-specific policy measures that marry concepts of gender and environment rather than treat them as separate ends.

Overall, while gender empowerment may and does impact economic and social organization, its effects on the environment are dependent on how it is cast in the broad patterns of development. This interplay remains to be unpacked by future research that may guide up policies fostering both gender equity and environmental sustainability.

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